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(54) System for reducing signal disturbances in ECG, which disturbances are caused by cardio-pulmonary resuscitation

(57) A system for reducing signal disturbances in ECG, which disturbances are caused by cardio-pulmonary resuscitation (CPR). The system includes a measuring device for measuring one or more signals derived from parameters such as compression depth, lung inflation etc. as a result of CPR. The parameter signals form one or more reference signals that correlate with the signal disturbances. One or more adaptive filters filter the signals out from the signal that constitutes the ECG signals.

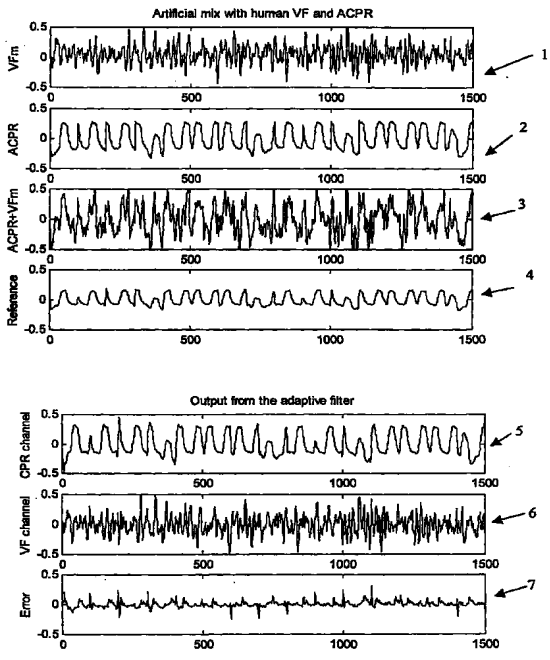

Fig 6

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Description

[0001] The present invention regards a system for reducing signal disturbances in electrocardiogram (ECG), which disturbances are caused by cardio-pulmonary resuscitation, as stated in the introduction to Claim 1.

[0002] The three primary means of treating sudden cardiac death are cardio-pulmonary resuscitation (CPR), defibrillator shocks and medication, cf. the publications [1] "Advisory Statements of the International Liaison committee on Resuscitation (ILCOR). Circulation 1997;95:2172-2184, and [2]"Guidelines for Cardiopulmonary Resuscitation and Emergency Cardiac Care". Journal of the American Medical Association, October 28 1992, Vol. 268 No 16: 2171-2302.

[0003] The normal course of action in the case of sudden cardiac death and a resuscitation attempt is to first administer CPR until the defibrillator arrives, and then alternate between shocks from the defibrillator and CPR until the patient has a distinct pulse or until an ALS team arrives (ALS=Advanced Life Support). Then, securing of the respiratory passages and use of medication will be included together with the alternating use of a defibrillator and CPR. The first step towards resuscitation is to restore spontaneous heart activity and sufficient blood pressure. This is often termed ROSC (Return of Spontaneous Circulation).

[0004] The protocol that guides the defibrillator—CPR treatment states that, upon arrival of the defibrillator, three shocks should be administered initially, followed by 1 minute of CPR, then three new shocks and so on [1]. In order to administer a shock, the ECG must first be measured, analysed and classified as "Treat" or "Notreat". Defibrillators of the automatic or semi-automatic type will do this automatically, and this type of defibrillator is often called an AED (Automated External Defibrillator). The part of the software that performs this classification is usually described as the VF algorithm. After concluding the rhythm, the defibrillator will ready itself for shock delivery, report its readiness to deliver shocks, and wait for the user to operate the shock button. This procedure takes time, and it takes about one minute to administer three shocks. This is time during which the patient does not receive CPR, and during which vital organs, especially the brain, is damaged further due to the lack of blood supply [1].

[0005] Furthermore, this procedure entails the shock being delivered approximately 20 seconds after the CPR has been concluded. Animal experiments have shown that the probability of achieving ROSC decreases rapidly with time from conclusion of the CPR. The best chance of achieving ROSC is through delivering the shock without delay following CPR, cf. the publication [3] by Sato Y, Weil MH, Sun S et al., titled "Adverse effects of interrupting precordial compressions during cardiopulmonary resuscitation" in Crit Care Med 1997;25:733-736.

[0006] Performance of CPR has a disturbing effect on the ECG signals. The disturbances take the form of rhythmic signals, and occur simultaneously with heart compressions or inflations. As heart compressions are administered at a rate of 80-100 per minute, these rhythmic disturbances will generally cause the VF algorithm to draw incorrect conclusions in those cases where the rhythm is VF (ventricle fibrillation) or VT (ventricle tachyardia). This is caused by the algorithm interpreting the rhythmic disturbances as a pumping rhythm; i.e. there is no requirement for defibrillator shocks. It is therefore normal procedure to use the VF algorithm only after CPR has been concluded, cf. publication [1].

[0007] The present invention regards a system that reduces the disturbances in the ECG during heart compression through use of adaptive digital filtering as stated in the introduction, the characteristics of which can be seen from Claim 1. Further characteristics of the invention appear from the remaining, dependent claims. Thereby the following advantages are derived:

- As the VF algorithm can conclude while CPR is being performed, this will lead to less time being used for shock delivery, thereby leaving more time for CPR.
- For the same reason, the shock may be delivered sooner following the conclusion of the CPR, something that will directly increase the probability of ROSC.
- It becomes possible to perform signal analysis of VF for other purposes than classification. A useful possibility is to measure the characteristics of the heart that may indicate how effective the CPR is.

[0008] In the following, the invention will be described in greater detail with reference to the drawings, in which:

Fig. 1 schematically shows a circuit diagram of the system according to the invention.

Fig. 2a shows the basic circuit arrangement for measuring the voltage between the patient and the measuring system when using a separate earth electrode Fig. 2b shows the basic circuit arrangement for measuring the voltage between the patient and the measuring system when not using a separate earth electrode

Fig. 3 shows the principle of the course of the signal in a digital adaptive filter.

Fig. 4 shows the elementary diagram for connecting the output signal to an external defibrillator, and for connecting the defibrillator shock to the electrodes.

Fig. 5a shows an application where the system is integrated into a defibrillator.

Fig. 5b shows an application where the system forms a functional unit connected to an

automatic CPR machine.

Fig. 5c shows an application where the system forms a self-contained unit, used with a defibrillator.

Fig. 6 shows an example of a signal sequence when using adaptive filtering, in which the signal disturbance is added to a clean VF signal and then filtered out through the use of adaptive filtering.

[0009] The system components may be split into the ECG measuring system, indicated by reference number 1 in Figure 1, and, as shown further in Figure 1, reference measuring system 2, analogue to digital converter (ADC) 3, processor and filter system 4, signal outlet 5 and electrodes 6.

[0010] The system may be used:

a) Integrated into a defibrillator.
b) As a functional unit connected to an automatic CPR machine.
c) As a self-contained system that can deliver a filtered ECG to a stand-alone defibrillator.

[0011] The following describes the above system components in greater detail:

ECG measuring system 1.

[0012] The ECG measuring system 1 consists of at least two electrodes 6 connected to the patient 25, cf. Figs. 5a-5b, a network that protects the inlet against overvoltage, as well as one or more buffers/amplifiers that deliver the result of the measurement to the ADC 3. In a defibrillator, this is normally part of the standard design.

Reference measuring system 2

[0013] The reference measuring system 2 consists of a sensor and signal processing for estimating the depth of the heart compressions 2a; possibly also a sensor and signal processing for estimating the lung inflations 2b and possibly also a sensor and signal processing for estimating the differential voltage between the measuring system and the patient 2c. Several techniques may be used for the estimation of compression depth: In the case of CPR, the impedance between two electrodes placed at standard defibrillation positions will be altered. By an approximately constant alternating current being impressed between the electrodes, the impedance change will be represented by a voltage change measured between the electrodes. The change in voltage expresses both heart compression and lung inflation, by the current path between the electrodes changing during CPR.

[0014] Alternatively, an accelerometer that follows the movements of the chest during heart compression via signal processing and conversion will express the depth of the heart compression. Alternatively, a linear position transmitter connected to e.g. an automatic CPR machine 28 will indicate the depth of the compression. Likewise, a sensor for measuring air volume or a sensor for measuring respiratory passage pressure may represent a signal for lung inflation. This type of signal is normally available from an automatic CPR machine 28, cf. Fig. 5b. The sensor for estimating the differential voltage between the measuring system and the patient may be a resistor and an amplifier. The connection may be effected in several ways, depending on the topology of the ECG amplifier. Fig. 2a shows the connection schematic with an earth electrode. Here, the charge equalisation between the patient and the measuring system will primarily go via the resistor 7, the voltage of which is measured by the amplifier 2c'. This voltage will then be correlated with the signal disturbances that are caused by charge equalisation and imbalance in the impedance between the patient 25 and each of the electrodes 6.

[0015] Fig. 2b shows the connection schematic in the case where the patient is not connected to earth. The charge equalisation between the patient and the measuring system will primarily go via the resistor 7, and then distribute via the resistors 8 and 9 to the patient 25 via electrodes 6. The voltage across the resistor 7 will then be correlated with the signal disturbances that are caused by charge equalisation and imbalance in the impedance between the patient 25 and each of the electrodes 6.

ADC 3

[0016] ADC 3 converts each of the analogue channels to a digital channel that can be read by the processor and filter system 4. In a defibrillator 26, ADC3 normally forms part of the standard design.

Processor and filter system 4

[0017] The processor and filter system 4 receives the raw data from the ADC 3 and sends the filtered data onwards. Adaptive digital filtering is used as the filtering method, cf. Fig. 3. This method has the special feature of being able to reduce disturbances that have a frequency distribution that overlaps the frequency distribution of the signal being disturbed. Furthermore, the method will adapt to changes in the signal disturbance with time. Disturbances that are caused by CPR will be of such a nature.

[0018] The main components in an adaptive digital filter are:

- The primary signal 10 is ECG with signal disturbances in digital form, and may be described through the formula:

$$d(k)=s(k) + n(k)$$

in which s(k) is the desired signal (pure ECG) and n(k) is the disturbance.

- The output signal e(k), indicated by reference number 11 in Fig. 3, is an estimate of the initial ECG signal after filtering.

- The output signal y(k), indicated by reference number 12 in Fig. 3, is an estimate of the initial signal disturbance.

- The reference signal r(k) is normally described as the filter input signal, and is indicated by reference number 13 in Fig. 3. r(k) correlates with the disturbance.

- Digital filter 14, typically a FIR filter with a number of taps, preferably 9.

- Adaptive process 15, methodology to adjust the parameters of the filter in such a way that the estimate e(k) converges to s(k), preferably of the type Conjugate Gradient, (CG).

[0019] The methodology in a digital adaptive filter is as follows: The expectancy value of the square of the output signal e(n) is minimised with regard to the filter coefficients. The filter will then make the filter output y(k) approximately equal to the signal disturbance n(k).

[0020] If several disturbances add up, a reference signal may be configured to correlate with the sum of the disturbances, or else a plurality of adaptive filters may be used in series, removing each disturbance in rotation. Before the reference signal continues to the filter, the amplitude and frequency content are adapted in 16 in accordance with the expected disturbance of the system in question, by removing the DC component and setting the mean amplitude of the reference signal 13 to a value approximately equal to half of the amplitude of the primary signal 10. The output signal then goes directly to the VF algorithm if the system is integrated into a defibrillator 26 (Fig. 5a, 5b, 5c), or to signal outlet 5 (fig. 1).

[0021] If the filter solution is not too complex relative to the processor capacity of the system, the best filter solution will be achieved by optimising the filter coefficient as a function of the Wiener solution, instead of an approximate solution obtained through using the Conjugate Gradient method for an approximate solution of the Wiener-Hopf equation.

Signal outlet 5

[0022] Signal outlet 5 is of interest in applications in which the defibrillator 26 is a stand-alone unit. The output signal is converted from digital to analogue form, and is made available to an external defibrillator. It may also be of interest to include components that connect the defibrillator shocks to the patient via the same electrodes as those used by the ECG measuring system.

[0023] A solution for this is shown in Figure 4, which shows an example of a basic circuit arrangement for the signal outlet. From the processor and filter system 4, the output signal 11 continues to a digital to analogue converter (DAC) 17, and from there to two drivers 18p, 18n, which output currents having a phase difference of 180°, and then on to a resistance network 19,20,21 that sets the amplitude and protects the drivers 18p, 18n. An external defibrillator will then be able to connect across the resistor 21 via terminals 22, and be able to measure an ECG in which the signal disturbances are reduced or completely eliminated. As the resistance of 21 is far greater than that of the body, most of the defibrillator shock will pass to the patient 25 via gas dischargers 23, 24.

[0024] Fig. 6 shows an example of the sequence of signals when using adaptive filtering, where the signal disturbance is added to a clean VF signal and then filtered out through use of adaptive filtering:

Curve 1 in Fig. 6 shows VF from a person, VFm, here without signal disturbance.
Curve 2 in Fig. 6 shows signal disturbances during CPR, measured on a pig.
Curve 3 in Fig. 6 shows the sum of signals 1 and 2, and represents a VF disturbed by CPR. This is the primary signal d(k).
Curve 4 in Fig. 6 shows the reference signal r(k), which is made up of the signal from the position transducer and from the impedance measuring system.
Curve 5 in Fig. 6 shows the output y1(k), which expresses the signal disturbance estimated by the filter.
Curve 6 in Fig. 6 shows the output e(k), which expresses the VF signal e(k) estimated by the filter.
Curve 7 in Fig. 6 shows the difference between the initial signal VFm and e(k), which also represents the error in the estimated signal.

Applications

[0025] The system may be used as an integrated part of a defibrillator, cf. fig. 5a, and will in this case be able to make use of components and solutions that are already a part of this; typically the ECG measuring system, the ADC, and the processor system. In addition to the adaptive digital filter, such a solution will also require a representative reference measuring system. In this case, the signal outlet will not be put to use, as the defibrillator uses a filtered ECG in a digital format.

[0026] A third attractive possibility is to connect the solution to an automatic CPR machine 28, cf. Fig 5b. This type of equipment is in general use in many ambulance systems, and will be able to administer high quality CPR over an extended time. Because the CPR is

automated, the defibrillator can deliver shocks simultaneously with the administration of the CPR, without the risk of exposing the lifesavers to high voltages. Thus there is no delay between the CPR and the shock delivery, a factor that is reported to increase the probability of ROSC.

[0027] A stand-alone system will be an attractive application for many users, as this allows the use of existing defibrillators. This is illustrated in Figure 5c. In this case, all the system components will be included.

Claims

1. A system for reducing signal disturbances in ECG, which disturbances are caused by cardio-pulmonary resuscitation (CPR), **wherein**
   a device for measuring ECG signals, as well as one or several devices for measuring reference signals that arise as a function of CPR, where reference signals represent measurements that are related to causes of signal disturbances in ECG, are connected to separate inlets to a computational unit, and wherein the computational unit is designed to calculate an estimate of the signal disturbance as a function of the correlation between the signal disturbance and the reference signals, and wherein the computational unit produces an output that represents the difference between the ECG signal and the estimated signal disturbance.

2. A system according to Claim 1, **wherein** the computational unit utilises one or more digital adaptive filters.

3. A system according to Claims 1-2, **wherein** the device for measuring compression depth as a reference signal is a computational unit that estimates the compression depth determined from the signal from an accelerometer designed to follow the movements of the chest.

4. A system according to Claims 1-2, **wherein** the device for measuring compression depth as a reference signal is a system for measuring the change of impedance in the chest during a chest compression.

5. A system according to Claims 1-2, **wherein** the device for measuring compression depth as a reference signal is a linear position transmitter installed on an automatic CPR machine.

6. A system according to Claims 1-2, **wherein** the device for measuring compression depth as a reference signal is a pressure sensor that reads the pressure that drives the piston in an automatic CPR machine.

7. A system according to Claims 1-2, **wherein** the device for measuring lung inflation as a reference signal is a system for measuring the change of impedance in the chest during a lung inflation.

8. A system according to Claims 1-2, **wherein** the device for measuring lung inflation as a reference signal is a pressure sensor that is connected to the patient's respiratory passage.

9. A system according to Claims 1-2, **wherein** the device for measuring lung inflation as a reference signal is a flow meter connected to the respiratory passage going into and out of the patient.

10. A system according to Claims 1-2, **wherein** the device for measuring lung inflation as a reference signal is a thermocouple that is actuated by the air flowing into and out of the patient.

11. A system according to Claims 1-2, **wherein** the device for measuring charge equalisation as a reference signal is a voltage meter (2c') connected to a resistor (7) that is connected between an earth electrode (6) running to the patient, and the earth potential of the ECG measuring system.

12. A system according to Claim 11, **wherein** the device for measuring charge equalisation as a reference signal is a voltage meter (2c') connected to a resistor (7) that is connected to a point that represents the mid-point of the potential between the electrodes (6) and the earth potential of the ECG measuring system.

13. A system according to Claims 1-12, **wherein** the system is integrated into a defibrillator.

14. A system according to Claims 1-13, **wherein** the system forms a functional unit connected to an automatic CPR machine.

15. A system according to Claims 1-14, **wherein** the system forms a self-contained unit that can be connected to a defibrillator.

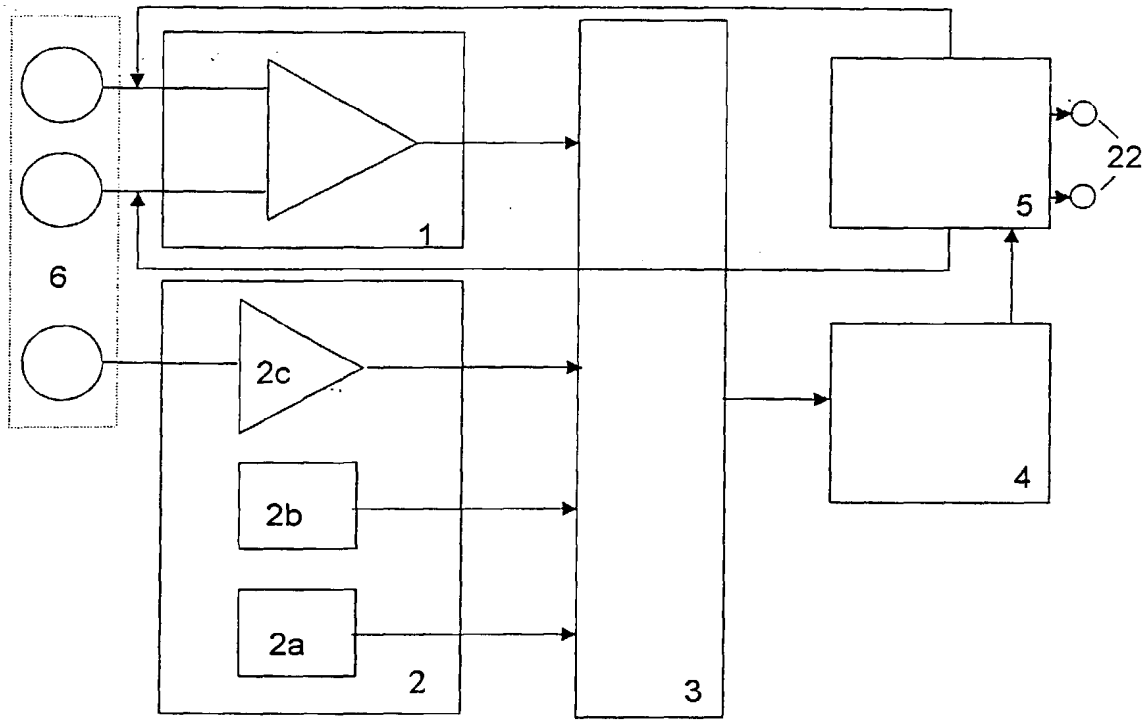


Fig. 1

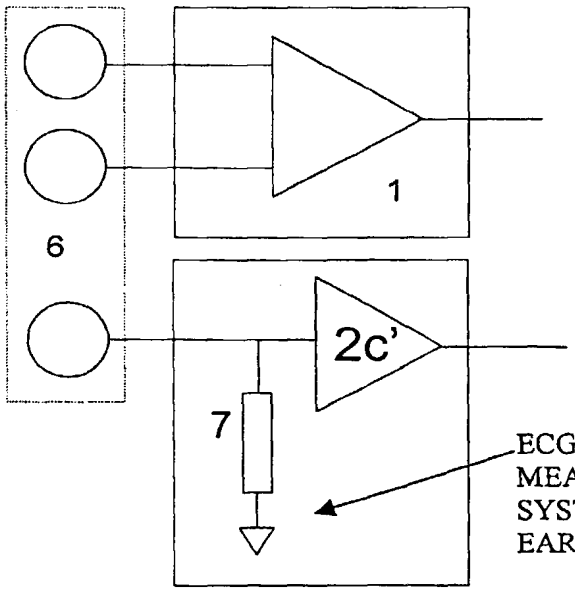


Fig. 2a

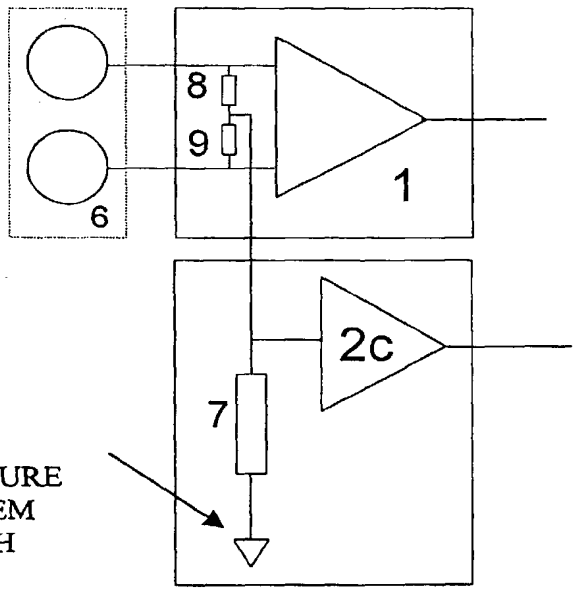


Fig. 2b

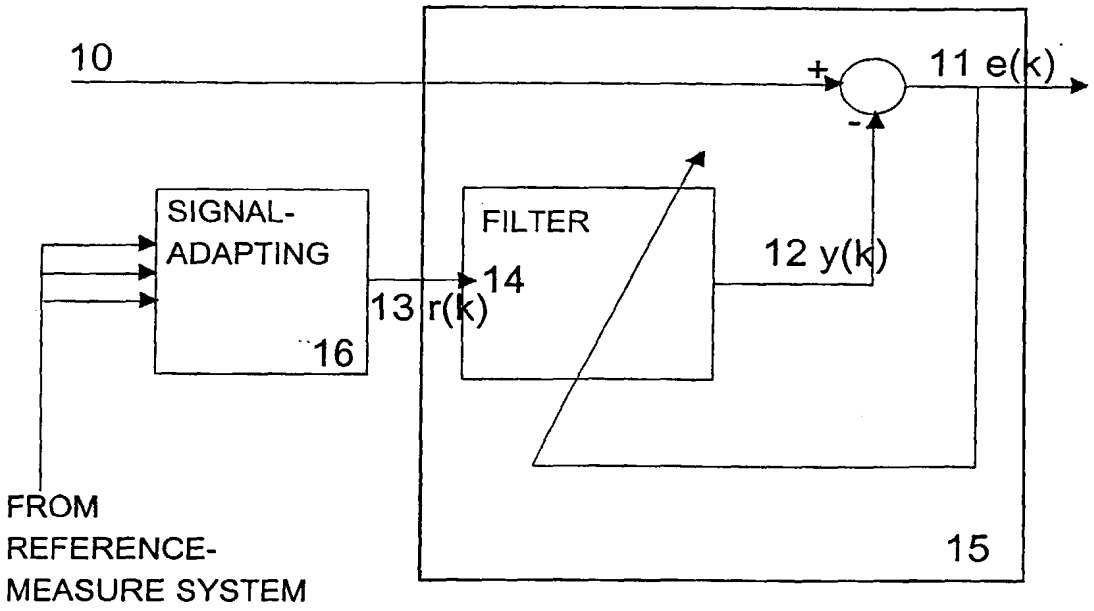

10
+
11 e(k)
-
SIGNAL-
ADAPTING
16
FILTER
14
13 r(k)
12 y(k)
FROM
REFERENCE-
MEASURE SYSTEM
15

Fig. 3

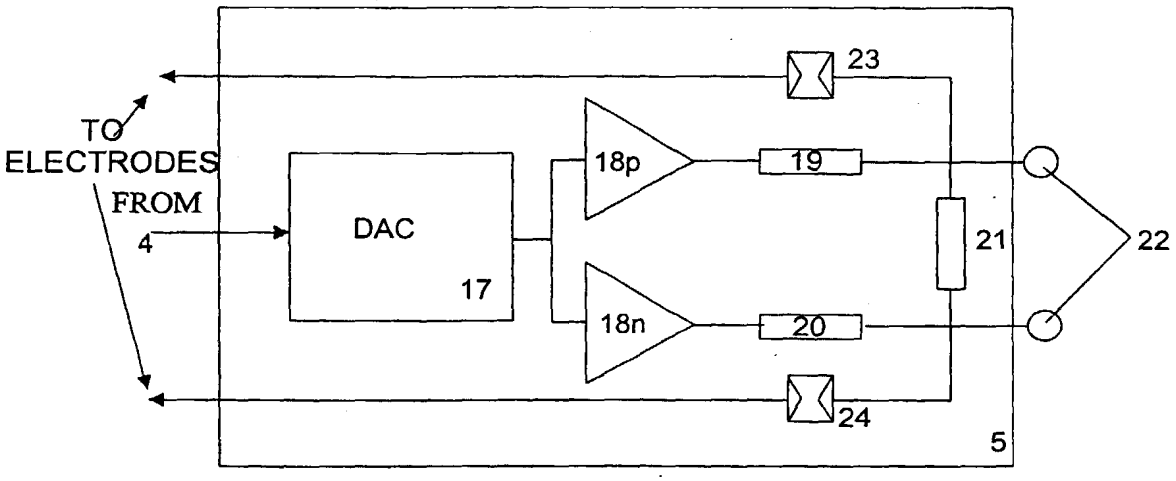

TO
ELECTRODES
FROM
4
DAC
17
18p
18n
19
20
21
22
23
24
5

Fig. 4

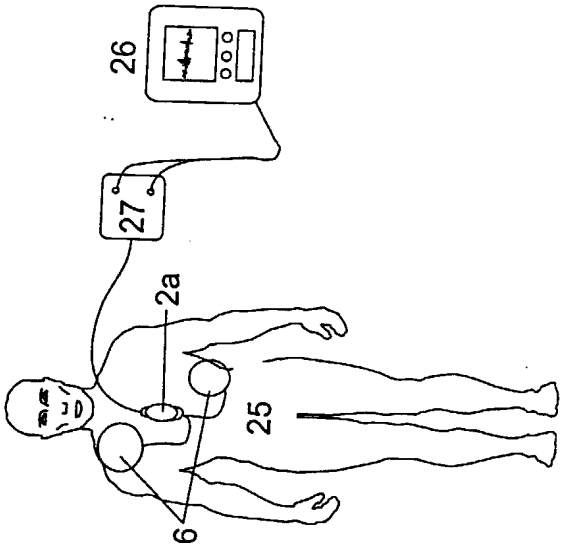


Fig. 5c

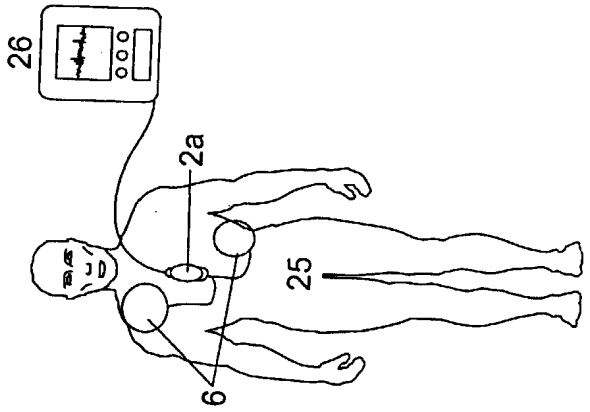


Fig. 5a

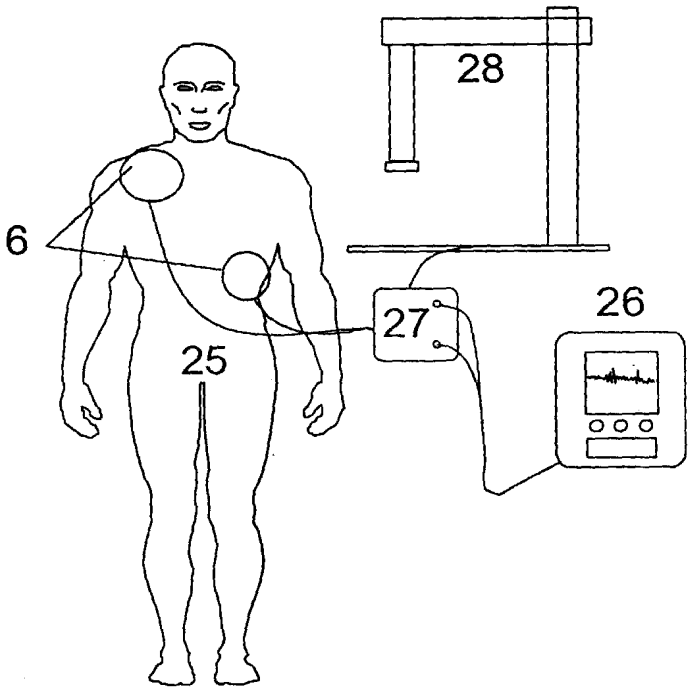
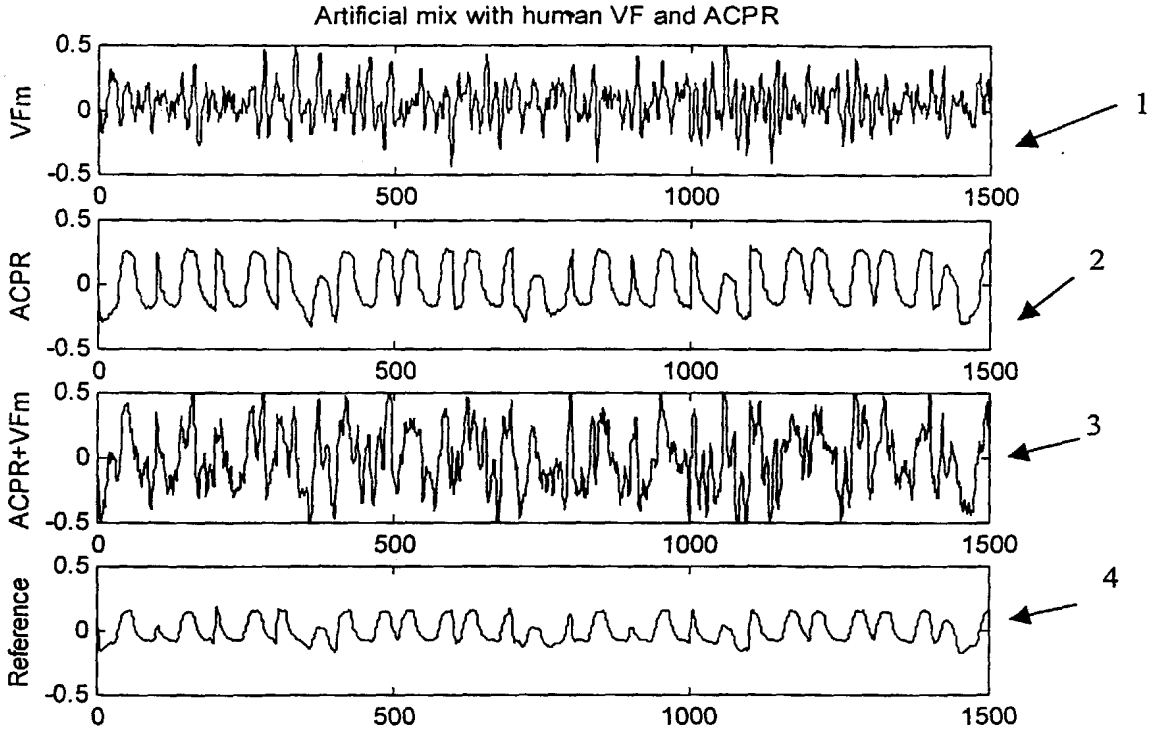


Fig. 5b


Artificial mix with human VF and ACPR
VFm
ACPR
ACPR+VFm
Reference
0.5
0
-0.5
0
500
1000
1500
1
2
3
4

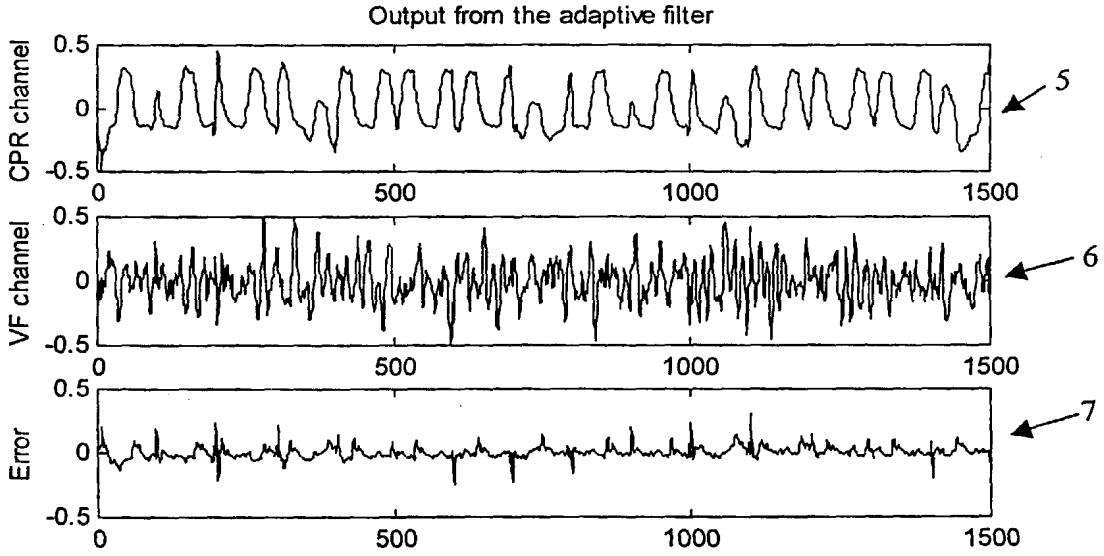

Output from the adaptive filter
CPR channel
VF channel
Error
0.5
0
-0.5
0
500
1000
1500
5
6
7

Fig 6

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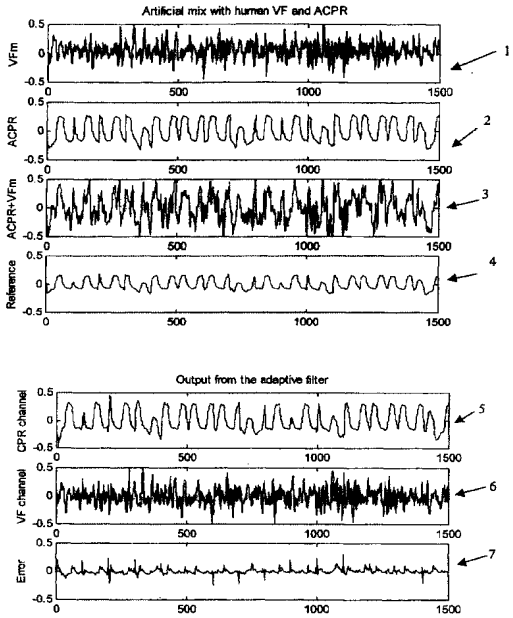

Fig 6

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European Patent Office

EUROPEAN SEARCH REPORT

Application Number
EP 00 11 7982

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int.Cl.7)
X	SHEN LUO ET AL: "Experimental study: brachial motion artifact reduction in the ECG" COMPUTERS IN CARDIOLOGY 1995 (CAT. NO.95CH35874), COMPUTERS IN CARDIOLOGY 1995, VIENNA, AUSTRIA, 10-13 SEPT. 1995, pages 33-36, XP002174432 1995, New York, NY, USA, IEEE, USA ISBN: 0-7803-3053-6 * page 33, left-hand column, line 28 - right-hand column, line 8 * * page 33, right-hand column, line 25 - page 34, left-hand column, line 21 * * page 34, right-hand column, line 2 - line 28 * ---	1-15	G06F17/00 G06F19/00
X	PROVAZNIK I ET AL: "Adaptive recurrent system for noise cancellation and arrhythmia detection" PROCEEDINGS OF THE 16TH ANNUAL INTERNATIONAL CONFERENCE OF THE IEEE ENGINEERING IN MEDICINE AND BIOLOGY SOCIETY. ENGINEERING ADVANCES: NEW OPPORTUNITIES FOR BIOMEDICAL ENGINEERS (CAT. NO.94CH3474-4), PROCEEDINGS OF 16TH ANNUAL INTERNATIONAL CONFERENC, pages 1270-1271 vol.2, XP002174433 1994, New York, NY, USA, IEEE, USA ISBN: 0-7803-2050-6 * page 1270, left-hand column, line 30 - right-hand column, line 27 * * page 1271, left-hand column, line 8 - line 45 * --- -/--	1-15	TECHNICAL FIELDS SEARCHED (Int.Cl.7) G06F

The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
MUNICH	9 August 2001	Barba, M

CATEGORY OF CITED DOCUMENTS

X : particularly relevant if taken alone
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P : intermediate document

T : theory or principle underlying the invention
E : earlier patent document, but published on, or after the filing date
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L : document cited for other reasons

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X	THAKOR N V ET AL: "Applications of adaptive filtering to ECG analysis: noise cancellation and arrhythmia detection" IEEE TRANSACTIONS ON BIOMEDICAL ENGINEERING, AUG. 1991, USA, vol. 38, no. 8, pages 785-794, XP002174434 ISSN: 0018-9294 * page 785, right-hand column, line 28 - page 787, right-hand column, line 13 * * page 788, left-hand column, line 4 - page 790, left-hand column, line 12 * * page 791, right-hand column, line 12 - page 793, left-hand column, line 56 *	1-15	

TECHNICAL FIELDS SEARCHED (Int.Cl.7)

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CATEGORY OF CITED DOCUMENTS

X : particularly relevant if taken alone
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A : technological background
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